DTIC FILE COPY

4

AD-A216 435

UNITED STATES NAVAL ACADEMY
DIVISION OF
ENGINEERING AND WEAPONS
ANNAPOLIS, MARYLAND

DTIC
ELECTE
DEC 28 1989
S B D

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

89 12 28 032

(4)

EW-1-90

January 1990

MATERIALS TRENDS IN MARINE CONSTRUCTION

C. R. Crowe* and D. F. Hasson**

*Naval Research Laboratory, Washington, DC 20375
**Mechanical Engineering Department
U. S. Naval Academy, Annapolis, Maryland 21402

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: EW-1-90	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE *(and Subtitle)*: MATERIALS TRENDS IN MARINE CONSTRUCTION	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): C. R. Crowe D. F. Hasson	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: United States Naval Academy Division of Engineering and Weapons Department of Mechanical Engineering	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: United States Naval Academy Annapolis, MD 21402	12. REPORT DATE: January 1, 1990
	13. NUMBER OF PAGES: 29
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*	15. SECURITY CLASS. *(of this report)*: UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Unclassified - Distribution Unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Marine grade steels; Welding, carbon equivalent; Graville diagram, weld defects, weld joints; titanium ~~and its~~ alloy; ~~composite~~, polymer matrix composites, marine applications of composites; marine concrete structures, engineered materials.

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The use of materials in high performance structural systems, such as, offshore platforms or habitats, surface ships and submersibles has emphasized the need for engineered materials. The use of metallic materials has the advantage of a large data base on the processing and fabrication effects on structural integrity. There is still the need to approach the overall design problem using a synergistic method to account for the interaction of the environment with thermal mechanical processing and weld fabrication aspects.

Although not discussed, the need for detailed maintenance and nondestructive evaluation inspection programs can not be under emphasized in order to insure structural integrity. While reinforced and prestressed concrete have been utilized successfully, polymer matrix composites require more realistic specifications for efficient weight and cost large structures. Joining methods for PMC materials must also be examined in much more detail.

MATERIALS TRENDS IN MARINE CONSTRUCTION

C.R.Crowe
Naval Research Laboratory
Washington, DC 20375
and
D.F.Hasson
U.S. Naval Academy
Annapolis, MD 21402

Introduction

The earth's blue color from space can be associated with the fact that three fourths of its surface is covered by the oceans. Hidden within and below this important resource are a food-bearing ecosystem, and energy and mineral reserves. The ecosystem even controls our climate a' la El Nino. In the forties of this century, it became technologically feasible to extract fossil energy by the construction of offshore oil platforms. Also, improvements in ship construction achieved by the use of tougher steels and improved welding techniques has provided increased structural integrity for safe shipment of oil. In addition, the same developments led to the fabrication of thin walled austenitic stainless steels for the bladders of liquefied natural

petroleum gas (LNPG) ship carriers. These successes have come about by an increased understanding of the interaction of various aspects of the ocean environment, such as, salinity, tides, temperature, oxygen concentration, wave characteristics and wind and water currents on materials used in marine construction. Other consequent environmental effects such as corrosion and biofouling must also be addressed as depicted in Figure 1.

In order to properly design for structural integrity, a synergistic approach must be employed by ocean scientists and materials and design engineers which integrates environmental, materials, and design aspects. Also important are testing, means of construction and fabrication, operation, and inspection and monitoring, including nondestructive evaluation (NDE). These constitute the state-of-the-art fracture control practices which are required to insure the structural integrity necessary to provide safe marine structures. If this goal can be achieved, it comes at a propitious time when our nation's natural mineral and energy sources need to be efficiently and safely extracted from their hidden source...the ocean. In addition to natural resources and a food-bearing ecosystem, giant floating platforms (1,2) could provide real estate for over populated areas or for specialized floating facilities, such as, airports, salvage and repair facilities and acquafarms.

Structural metallic materials are dirvided into ferrous (eg. steels) or non-ferrous (eg. aluminum and titanium) metals and alloys. Marine grade steels comprise about 90-95 of marine structural applications. Since most marine structures and systems are produced from steels, this paper will discuss the importance of metallurgical factors such as, mill practice, microstructure, thermomechanical treatment, and fabrication procedures (e.g., welding) of steels. Because of relatively low costs and rapid construction most marine structures are

fabricated by welding, and many of the critical structural integrity constraints are associated with welding. The extensive use of welding has led to many welding related catastrophic failures which are a source of economic and human loss. An example of a modern welding related failure is the collapse of the mobile offshore platform Alexander Kielland in the North Sea on March 27, 1980. The Alexander Kielland was a drilling rig that had been converted to an accommodations platform. The rig capsized in heavy seas (20 m/sec winds and 6 to 8 m waves), killing 123 of the 212 onboard. The cause of the disaster was attributed to a 6 mm fillet weld which joined a non-load bearing flange to one of the main braces (9).

Metallic corrosion behavior and protection, however, will not be examined, but several articles (3-8) are recommended to the reader who requires information on these important topics.

While examining the various trends in marine steels a brief introduction to welding is included to illustrate some of these aspects. The overall presentation also includes some remarks, on titanium and its alloys, as well as information on nonmetallic materials, specifically polymer matrix composites and prestressed and reinforced concrete for marine applications.

STEELS FOR OFFSHORE STRUCTURES AND SHIPS

Steel alloys are usually selected as materials of construction because of their relatively low cost, ease of fabrication by welding, and moderately good mechanical properties. Commercial marine grade carbon steels are iron-based alloys with carbon and other alloying

additions, principallyy manganese. These steels are delivered from the steel mills with various yield strength levels in the range 270 MPa to 690 MPa in various grades within each strength level classification. The factors that affect the properties and quality of mill steels are listed in Table I. The various grades provide differing fracture toughness and weldability.

TABLE I

FACTORS AFFECTING THE MICROSTRUCTURE OF MILL STEELS

Chemical Composition
Melting Practice
Type And Extent Of Deoxidation
Special Processing (Vacuum Degassing, Desulphurization)
Grain refining
Rolling Procedure (Controlled Rolling, Quenching)
Heat Treatment (Normalizing, Quench & Tempering)

The appropriate choice of structural steel should conform to the specifications for steels published by the classification societies. The American Bureau of Shipping (ABS), The American Petroleum Institute (API), LLoyd's Registry, Det Norske Veritas, the Department of Energy-Petroleum Engineering Division of Great Britain, and the US Navy are examples of organizations providing specifications for alloy selection for marine construction.

Table II lists typical chemical compositions of some higher strength marine grade steels. The majority of steels used in the commercial marine industry are carbon-manganese steels, illustrated by ABS EH 36 in Table II. These steels typically have less than 0.15% carbon and yield strengths less than about 360 MPa. The microstructure of the steels is usually acicular ferritie, bainite, and/or pearlite and they derive their strength from fine grain size.

TABLE II
TYPICAL COMPOSITIONS OF MARINE GRADE STEELS

ELEMENT	ABS EH36	EH36 Mod	HTS	HY80	HY100	HSLA80	HSLA100
C	0.07	0.07	0.18	0.18	0.2	0.07	0.04
Mn	1.5	1.5	1.6	0.3	0.3	0.05	0.9
Si	0.3	0.3	0.3	0.2	0.2	0.04	0.27
P	0.02	0.02	0.04	0.025	0.025	0.025	0.008
S	0.002	0.002	0.04	0.025	0.025	0.025	0.002
Cu	0.2	0.2	0.35	0.026	0.25	1.2	1.58
Ni	0.35	0.35	0.4	3.25	3.5	0.8	3.55
Al	0.07	0.06					
Ti		0.007			0.02		
Cr			0.25	1.5	1.5	0.07	0.6
Mo			0.08	0.5	0.5	0.2	0.6
V			0.1	0.03	0.03		
B							
Nb			0.05			0.02	0.3
CE	0.36	0.36	0.58	0.85	0.91	0.27	0.77

In some offshore platform and ship construction, higher strength and toughness are required. In these applications steels such as HTS, HY80 and HY100 are used. These are quenched and tempered (Q&T) steels which derive their strength from the martensitic microstructure resulting from the carbon addition to the alloy. In thicker sections, some bainite is also observed. The other alloying elements added serve a variety of purposes. Nickel and

chromium are added to increase toughness and both nickel and molybdenum are used to control the response of the alloy to the Q&T heat treatment. Molybdenum is also added to minimize susceptibility to temper embrittlement. Manganese is added to scavenge sulphur which precipitates in the form of manganese sulphide inclusions in the alloy.

Over the last ten years, however, major changes have occurred in the use of higher strength steels (up to 680 MPa yield strengths) in construction of offshore structures and ships (10,11). Modified or new alloy chemistries combined with modern steel making practices and with advanced thermomechanical processing have produced several steels that possess desirable toughness and weldability characteristics when compared with steels traditionally used to construct marine structures. The reasons for this increased usage at high stress levels is because of improvements in weldability and low temperature toughness which are achieved in a cost effective manner.

The modern approach to improved steel plate properties is to use microalloying and thermomechanical processing to precipitate fine dispersions and to refine the microstructure of the steel. Thermomechanical controlled processed steels (TMCP) achieve their improved mechanical properties by precise control of impurity levels, rolling temperatures, rolling reductions, and cooling rates in alloys with modest carbon equivalents. This thermal mechanical processing leads to fine grain size in the alloy. Modified marine grade steel chemistries as well as other high strength, low alloy steels benefit from thermomechanical controlled processing. Typical alloy compositions are listed in Table II as EH 36 mod and HSLA 80. This latter composition is also designated as ASTM 710. While the addition of Ti and Cu provide precipitation of desireable phases in their respective alloys, reducing sulphur,

oxygen, nitrogen, and oxygen in the steel improves toughness by reducing the number and size of undesireable inclusions of both the base plate and in the heat affected zones (HAZ) adjacent to weldments. While the details of the thermomechanical processing are proprietary, the rolling of the steel is generally performed at lower temperatures around the A_3 where the initial rolling produces a finer austenite grain size. Subsequent rolling stages consist of high reductions in the austenite recrystallization region to promote a still finer austenite grain size, and high reductions in the austenite non-recrystallization region but above the austenite transformation temperature to promote deformation bands for subsequent fine grain nucleation. The use of accelerated cooling or direct quenching and tempering after rolling permits steels of chemistries of much lower carbon equivalent without loss of strength. The process is illustrated in Figure 2 which shows how different processing sequences lead to fine grain size within the steel plate.

Today commericial treatments used in producing mill products usually assure that the steel will exhibit the properties attributed to that alloy when it is received by the customer. However, subsequent working or thermal treatments applied during secondary fabrication, especially during welding, can and often do alter the properties of the alloy.

The welding processes utilized for joining steels in the ship and offshore platform industries are shielded metal are welding (SMAW): 50%, submerged metal arc welding (SAW): 15%; CO shielded gas metal arc welding (GMAW): 30%; with gas tungsten arc welding (GTAW) and electroslag welding (ESW) providing the remainder. GMAW is used more for the high strength quenched and tempered steels, while GTAW is used on a limited basis to remelt the weld toe to improve fatigue resistance of welds. ESW is used for high weld metal deposition rate in thick sections (12). Other processes currently in development are flux core and narrow-

gap welding. All aspects of welding fabrication processes, equipment, and filler materials are described in a multi-volume set of references from the American Welding Society (AWS) (13) and Volume 6-Welding Brazing and Soldering from ASM International (14).

A weld consists of three principal regions, the weld metal, the heat affected zone (HAZ), and the parent metal. Figure 3 shows a schematic of the cross-section of a typical weldment along with a representation of a portion of the phase diagram of steel. The weld metal is a casting that reflects the alloy composition of the consumable filler material as mixed with dissolved parent metal. It displays a deposit structure and segregation of alloying elements dependent on the welding conditions. The solidified weld metal contains large columnar grains, which have strength and toughness properties different from the base metal. The HAZ occurs because of the thermal history that the parent material experiences during welding. Materials close to the weld will be heated from a peak temperature of the melting point at the fusion boundary to ambient temperature some distance away. The thermal history is position dependent, and the metallurgical changes occurring in the HAZ result from this thermal history. A fundamental understanding of the effects of the nonequilibrium thermal history which occur during welding is required to understand and achieve control of the welding process. The key to this understanding are the continuous cooling transformation curves (C-C-T) for the specific alloys which are being welded as depicted schematically in Figure 4.This figure summarizes the conditions of the primary phase transformations occuring in the steel. Conventional high strength and ordinary steels welded with high heat input processes exhibit grain coarsening in the HAZ. Recrystallization and grain growth, phase changes, and precipitation produce the structure of the HAZ. The coarse grains in the HAZ of the base plate have higher hardenability than the base metal, and consequently demonstrate a

greater tendency to form hard, brittle martensite and often have low fracture toughness. These coarse grains are delineated by proeutectiod ferrite nucleated and grown from prior austenite grain boundaries. Large amounts of Widmanstaten secondary plates also develop from grain boundaries producing the low toughness microstructure. This may produce microcracking after welding.

The local expansion and contraction associated with fusion welding usually results in the development of residual stresses on cooling to ambient temperatures. These residual stresses act in concert with those that are applied to the structure and therefore play a part in the mechanical response of the steel to loads. Residual tensile stresses are deleterious and are avoided if possible. In instances where residual stresses present problems, proper post-weld heat treatment and/or mechanical working techniques to reduce the residual stress level should be applied.

Welding of metallic materials is qualified by the term weldability. Weldability is defined as the capacity of the metal to be joined satisfactorily. The criteria indicating the suitable joining of metals must be defined in metallurgical terms. The criteria are: (1) metallurgical compatibility for a specific process, i.e., how the weld region properties differ from the surrounding base metal: (2) ability to produce mechanical soundness, as indicated by lack of porosity, inclusions, or undesirable phases; and (3) serviceability under special requirements, such as fatigue and corrosion. Weldability tests and their ability to predict fabrication and service performance are discussed in detail by Brosilow (15).

It is generally recognized that the most effective way to improve weldability is to reduce the carbon equivalent of the steel. The carbon equivalent is an index which provides a means of

assessing the weldability of steels based on the composition of the steel. Several carbon equivalent relations exist, the most common being the International Institute of Welding (IIW) index:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \qquad (1)$$

where the concentrations of each element (C, Mn, Cr, Mo, V, Ni, and Cu) is in weight percent.

The relation between the carbon equivalent and carbon content of steels and their susceptibility to HAZ cracking is illustrated in the Graville diagram shown in Figure 5 (16). The use of the carbon equivalent index reflects, in compositional terms, important metallurgical characteristics of the steel that affect the properties of the welded material. These properties include the martensite start temperature, Ms, and whether the pearlite and bainite start boundaries move to longer times due to the addition of substitutional elements in the steel alloy. These metallurgical effects are reflected in the C-C-T curve for the steel alloy. The carbon equivalent will therefore indicate the type of microstructural constituents to be expected in the HAZ. The undesirable microstructural constituent is martensite, which is the hardest and most fracture prone constituent formed in steel.

Good weldability is achieved by using steels with controlled alloy chemistry and controlled welding procedure. The carbon equivalents of the alloys listed in Table II are shown in the bottom row of that table. A value of CE <0.43 is often considered necessary to achieve good weldability. Carbon equivalents for standard normalized or controlled rolled steels are

typically 0.40% to 0.42% whereas the the carbon equivalent of the HY steels is on the order of 0.7%. TMPC steels have carbon equivalents in the range 0.28% to 0.39%. The lower carbon equivalents provide good weldability but also lower the strength potential derived from alloy hardening. Lowering the carbon equivalent of a steel reduces the likelihood that the welded steel microstructure contains brittle, high hardness untempered martensite.

The high strength martensitic steels such as HTS, HY 80, and HY 100 require costly, stringent welding process control and specially designed filler metals to retain adequate properties in the as-welded condition. In some high carbon steels, formation of martensite can be avoided by preheating. HTS and HY steels must be preheated prior to welding and very carefully welded to achieve high quality joints. This procedure causes slower cooling rates and provides sufficient time to form the softer transformation products of pearlite and proeutectoid ferrite in the microstructure. In alloy steels with high hardenability, it is almost impossible to avoid formation of martensite, irregardless of plate thickness, thermal conductivity, weld geometry, and heat input level.

The effects of impurity elements in steel can be most deleterious to weldability. Phosphorus and sulphur, which seem to be inherent in steel making, are such troublesome impurities that strict control of their concentrations in the steel is required to maintain toughness. Other tramp elements such as antimony, arsenic, and tin have also been determined to cause embittement along with phosphorus in alloy steels with 3% to 5% nickel. These steels are typically stress relieved at temperatures that cause stress relief embittement (SRE). SRE is caused by enhanced diffusion due to nickel in the alloy of the impurity elements to the

grain boundaries. This segregation of impurity elements causes low energy intergranular failure from impact loading.

Good weldability under shipyard conditions is often difficult because control of the thermal history of the steel and its weldment is limited by the size of the structure, complex weld procedures, and difficult preheat conditions. If CE <0.41, Lloyd's Rules do not require preheating of the weld area. When the CE is as high as 0.45, low hydrogen electrodes and preheating are required, especially for situations where high restraint occurs or where low service temperatures occur.

The ease of producing sound welds also depends to a significant degree on the welding position. Welding positions which are applicable to all types of welding are the flat, horizontal, vertical, and overhead. The flat welding position is the easiest and best welding position. The other three welding positions are considered out-of-position and usually require special procedures to ensure good welds. For ship building and offshore platform construction, out-of-position procedures are required. To help alleviate these difficulties, shielded metal arc welding fluxes have been developed so that all position welding can be performed with fixed direct current, reversed electrode polarity (DCRP) power supplies.

The amount of welding in offshore structures and ships is so large that weld defects can not be avoided. The problems encountered in welding carbon, carbon-manganese, and low alloy steels are listed in Table III. Of the various defects, four are from the heat-affected zone--specifically, liquidation cracking, lamellar tearing, cold or hydrogen cracking, and reheat cracking. three types of cracking phenomena are associated strictly with the weld deposit,

namely, hydrogen attack, gas porosity, solidification cracking, and inclusions from arc strikes or improper descaling. Other defects associated with welding are related to the weld profile. Undercutting reduces the cross section and also acts as a stress riser, and residual stresses can cause formation of cracks. These defects are especially critical to structural integrity.

TABLE III

TYPES OF CRACKING PHENOMENA ASSOCIATED WITH WELDING

CRACKING PHENOMENA	POSITION IN WELDMENT
Cracking Phenomena	Position in Weldment
Hydrogen attack	Weld Deposit
Gas Porosity	Weld Deposit
Liquation cracking, HAZ burning, or hot tearing	Fusion Zone
Lamellar tearing	HAZ
Cold cracking or hydrogen cracking	HAZ
Reheat cracking	Weld deposit and HAZ

Thin plate (less than 6.5 mm) can be welded by a single pass (a pass is called a "bead"), but in heavier plate, depending on the weld process, the weldment can require multiple passes. In the fabrication of tubular steel platforms, there are four types of welded joints namely, T, K, T-K, and Y joints, as illustrated in Figure 6. The welds around all these

joints are of the fillet type, in which flaws such as undercuts, overbeading, and lack of penetration often occur (eg. underbead and toe cracks).

The fatigue behavior of welded joints is critical for structural reliability. The region most subject to stress is in or near the toe of the weld, where the weld metal meets the parent metal. This region is usually the site of fatigue crack initiation. Reducing the reinforcement height, good weld contour, and/or GTAW remelting in the toe/base metal can improve fatigue resistance. Fatigue crack initiation, fatigue crack propagation, and residual strength of the material when cracks are present affect the failure of the structure. The type of loading, the presence of flaws, and the microstructure of the material play significant roles in the material's performance.

For a sound weld, two key factors affecting weldment fatigue resistance are geometric stress concentration and residual stresses. A prime example of a geometric stress concentration at sites where fatigue cracks initiate are the toe of the weld at the intersection of the HAZ and the weld metal, as shown in Figure 7. Good bead contour at the toe of the weld can avoid the formation of a mold at the intersection of the toe and base plate which could act as a fatigue crack initiation site.

Alternate Marine Materials

Titanium and Its Alloys Titanium and its alloys were recognized as excellent choices for marine applications almost four decades ago by Williams (17). Their strength-to-weight ratios are higher than copper-nickel alloys and marine grade aluminum alloys, and thus they are the best for light weight structure and/or deep diving vehicles. Their high melting points makes

them attractive as replacement for lower melting point ship superstructure materials, such as, aluminum alloys. Their corrosion resistance is the highest of the structural metal alloys. Their cavitation resistance makes them most attractive for propulsors. These capabilities and comparisons to other materials are covered in detail for seawater piping systems, deep sea exploration and offshore oil drilling in references 18 to 20, respectively. Some of the titanium alloys and their marine applications are given in Table IV. One of the most successful deep diving research vehicles has been ALVIN with maximum operating depth to 12000 feet. The fabrication details are shown in Figure 8. To obtain a comparative depth diving vehicle the Academy of Sciences of the USSR cooperated with Oceanics of Rauma-Repola Subsea Technology Group of Finland to manufacture a personnel sphere which consists of two cast steel hemispheres (21).

TABLE IV

TITANIUM ALLOYS FOR MARINE APPLICATIONS

TITANIUM ALLOY	MARINE APPLICATION	FEATURE
Unalloyed Ti	Piping, Heat exchanger tubing, tube sheets	Good balance of strength and ductility
Ti-3Al-2.5V	High pressure piping systems	High strength and satisfactory ductility
Ti-6Al-4V (Cast)	Propellers	Cavitation resistance
Ti-621/0.8	Deep diving submersibles	Yield strength at least 100 ksi and best weldability

The widespread use of titanium and its alloys in marine structures especially large structures, such as, offshore platforms is limited due to cost and availability of some of the alloys. On the other hand, an overstated concern is weldability Let it be noted that with suitable attention to welding details titanium alloys especially of the non-heat treatable type, such as, Ti-621/0.8 can be successfully welded by all inert and protective processes, such as, GMAW, GTAW, ESW, FCAW, electron beam and laser welding (22,23).

Composites Man-made structural composites were known in Biblical times when straw was added to a clay matrix for building blocks. Possibly predating this practice the construction of boats involved a combination of structural constituents, such as, wood, other fibrous materials and natural binders. In more recent times marine vessels were constructed using E glass fiber in a polyester ester resin matrix (24). This material was called glass reinforced plastic (GRP), and this material, glass reinforced polyester became the forerunner of what we today call a "composite". Actually due to the matrix this is a polymer matrix composite (PMC). Of the three matrices, namely, metal, ceramic, and polymeric, PMC's are by far the most produced. Two and a half million pounds of reinforced polymer composites were produced in 1987 which was nearly an 8 percent increase over 1986 (25). While aerospace and automotive applications were 65 percent, marine applications represented a significant usage at 5 percent. Presently, however, most of this usage is for leisure craft, such as sail and motor boats.

One of the most attractive properties of PMC's are their strength-to-weight ratios which are higher than for some marine steels and aluminum alloys as given in Table V. This

TABLE V
TYPICAL MATERIAL PROPERTIES AND COSTS

MATERIAL	Matrix	Fiber Weight Fraction	Density of Laminate (g/cm^3)	Ultimate Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Ultimate Comp Strength (MPa)	Ultimate Strength to Density Ratio	Material Cost ($/lb)
Steel Corten 'A'	-	-	7.75	480	207	340	62	0.3
Al 5083	-	-	2.76	275	69	120	100	1.5
E Glass Woven Roving	Polyester	0.50	1.63	210-300	12-21	150-270	156	1.3
S Glass Woven Roving	Polyester	0.50	1.64	440	20	210	268	4.0
Aramid (Kevlar 49) Woven	Polyester	0.44	1.31	430	26	115	328	12.4
Carbon Fiber Woven	Polyester	0.44	1.40	460	30	-	330	25.9
Aramid (Kevlar 49) Woven	Cold Cured Epoxy	0.55	1.31	450	30	180	344	20.7

advantage can offset some of the present high cost per pound ratios given in Table V. Also, fabrication costs can be less than for metallic structures (24).

Marine applications of PMC's have been on the increase in both number, size and complexity. For example, a 189 foot long--39 foot beam fiber reinforced plastic (FRP) structure for a U.S. Navy mine sweeper represents the largest ship structure to date (26). The ship's hull construction consists of sheets of two layer foam core attached to a frame consisting of a male mold and FRP laminate which is applied to the outer hull. Between 10 to 15 plys of laminate are used which with the foam core make the hull 2 inches thick. Other naval uses include a net-shape molded composite propeller, light weight composite hatch doors and an aramid honeycomb with E-glass reinforced phenolic skin for ship superstructure (27). There is a definite role for PMC's in marine structures especially where structural weight is sensitive. Costs which include overall materials and fabrication costs can be competitive, but an unusual consideration could inhibit their use, specifically the lack of design standards. As noted by Marchant and Pinzelli (24), the marine Classification Societies (eg. Lloyd's Register of Shipping, Det Norske Veritas, American Bureau of Shipping and American Petroleum Institute) don't have the extensive technology and financial base of the aerospace industry to rapidly upgrade their Rules. Also, the present rules that the Societies have are conservative, and the potential advantages of PMC's for large structure such as, offshore platforms can not fully be realized. If this problem can be alleviated, the market potential is enormous.

Other design aspects for the application of PMC's in marine applications have been and are being addressed. For example, early work by Macander and Silvergleit (28) showed that properly designed and fabricated graphite/epoxy laminates can maintain structural integrity

when exposed to the marine environment. However, recent work at the University of Rhode Island flags a note of caution. Exposure of a vinyl ester/graphite fiber composite in sea water for four months at 2000 feet depth produced a loss of flexural strength of 20 percent in the composite (29). Another area which is presently receiving attention is the joining of PMC's. The criticality in joining is related to the prolific development of many new materials which have appeared more rapidly than the industry can fully characterize them (30). In order for PMC's to be used in critical structural applications the quality of the weld or bond must be improved and the effect of fabrication procedures must be better understood. The Edison Welding Institute at Ohio State University has most recently addressed this area by creating a group dedicated to the joining of plastics.

Another composite material that is utilized in marine structures is reinforced and prestressed concrete. Applications have been for large offshore gravity structures in Norton Sound and the Canadian Beaufort Sea. The water depths are shallow compared to other offshore structures. The arctic condition of high ice loads, however, places the design emphasis on the concrete structure to withstand high horizontal shear loads (31). An extensive discussion is provided by Gerwick on the materials design, durability, construction and structural applications of concrete for marine structures, such as, piers, seawater pumping plants, offshore platforms, breakwaters and floating structures (32). Specifications for the design and construction of prestressed and reinforced structures are found in British Standard CP 110 Structural Use of Concrete (33), and Design and Construction of Concrete Structures, published by Federation Internationale de la Preconstrainte (34).

Summary

The use of materials in high performance structural systems, such as, offshore platforms or habitats, surface ships and submersibles has emphasized the need for engineered materials. The use of metallic materials has the advantage of a large data base on the processing and fabrication effects on structural integrity. There is still the need to approach the overall design problem using a synergistic method to account for the interaction of the environment with thermal mechanical processing and weld fabrication aspects. Although not discussed, the need for detailed maintenance and nondestructive evaluation inspection programs can not be under emphasized in order to insure structural integrity. While reinforced and prestressed concrete have been utilized successfully, polymer matrix composites require more realistic specifications for efficient weight and cost large structures. Joining methods for PMC materials must also be examined in much more detail.

References

1. Ramsay, R. (1989), "The Military Potential of Semisubmersible Platforms," Sea Technology, February, 57-58.

2. Anon (1989), "Giant Platforms Key to Economic Use of Oceans," Sea Technology, May, 29-30.

3. Koch, G. H., Beavers, J. A. and Berry, W. E. (1988), "Marine Corrosion," in Materials for Marine Systems and Structures," (D. F. Hasson and C. R. Crowe, eds.), Academic Press, Inc., Boston, 122-243.

4. Jenkins, James F. (1988), Ibid, 277-350.

5. Heidersbach, R. and Smart, J. (1988), Ibid, 245-276.

6. Decarlo, G. (1981), "Computer Techniques for Offshore Corrosion Protection," Sea Technology, September, 25-30, 37.

7. Lee, T. S. (1983), "Seawater Velocity Effects on Corrosion Behavior of Materials," Sea Technology, November, 51, 53, 55, 56, 59.

8. Rumble, Jr., J., Anderson, D. and Kanfina, J. G. (1989), "Computerized Material Property Data Systems," Sea Technology, June, 42-45.

9. Anon (1981), "The Alexander L. Kielland - Accident," Norwegian Police Reports, NOU.

10. T.W. Montemarano, B.P. Sacks, J.P. Gudas, M.G.Vassilaros, and H.H.Vanderveldt, (1986) "High Strength Low Alloy Steels in Naval Construction," J. Ship Production, Vol 2, 145-162.

11. I.L.Stern, M.Wheatcroft, D.Y.Ku, R.F.Waite, and W.Hanzalek, (1988), "High-Strength Steels Produced by Advanced Metallurgical Processes," J. Ship Production, vol 4, 169-185.

12. Palko, W. A., Hasson, D. F. and Zanis, C. A. eds., (1985), Electroslag Processing for Marine Applications, Report EW-20-85, ADA 166926, U.S. Naval Academy, Annapolis, MD.

13. Kerns, W. H. ed. (1978), Welding Handbook, 7th Edition, American Welding Society, Miami, FL.

14. Anon (1983), Metals Handbook Vol. 6: Welding, Brazing and Soldering, ASM, Int'l Metals Park, Ohio.

15. Brosilow, R. (1978), "Weldability - What It Means to Fabricators," Welding Design and Fabrication, June, 74-80.

16. B.A.Graville,(1986), "Determining Preheat Requirements for Structural Steels," presented at AWS Annual Meeting, Atlanta.

17. Williams, W. L. (1950), "The Titanium Program at the U.s. Naval Experiment Station," Journal of the American Society of Naval Engineers, Vol. 62, No. 4, November.

18. Shultz, R. W., and Scaturro, M. R. (1988), "Titanium Outperforms Rivals for Improving Seawater Systems," Sea Technology, June, 49-57.

19. Crowe, C. R. and Hasson, D. F. (1981), "Titanium for Deep Sea Exploration," in Titanium in Industrial and Energy Applications," (D. Eylon, ed.), The Metallurgical Society, Warrendale, PA, 93-110.

20. Hasson, D. F. and Crowe, C. R. (1982), "Titanium for Offshore Oil Drilling," Journal of Metals, Vol. 34, No. 1, 23-28.

21. Simpson, J. P. (1989), "Soviet Submersible Built in Finland," Office of Naval Research, London, ESNIB 89-03, 51.

22. Hasson, D. F. (1986), "A Review of Titanium Welding Processes," NTIS Document No. ADA166442.

23. Anon (1989), "ESW Joins Titanium Alloy," Welding Design and Fabrication," August, 18.

24. Marchant, A. and Pinzelli, R. F. (1987), "Composites for Marine Structures - Where is the Future?" in "Looking Ahead for Materials and Processes," (J. de Bossu, G. Briens and P. Lissac, eds.), Elsevier Science Publishers, R. V., Amsterdam, 257-270.

25. Kubel, Jr., E. J. (1988), "Reinforced Polymers composites on the Move," Advanced Materials of Processes, vol. 133, No. 5, May, 29-31, 34-35.

26. Lodge, C. (1986), "Anchors Aweight for Construction of Largest FRP Ship," Plastics World, April, 9-10.

27. Pegg, R. L. and Reyes, H. (1987), "Progress in Naval Composites," Advanced Materials and Processes, Vol. 131, No. 3, March, 34-35, 38-40.

28. Macander, A. and Silvergleit, M. (1977), "The Effect of the Marine Environment on Stressed and Unstressed Graphite/Epoxy Composites," Naval Engineers Journal, August, 65-72.

29. Tucker,W.C.and R.Brown(1989),"Moisture Adsorption of Graphite/ Polymer Composites Under 2000 Feet of Seawater",Journal of Composite Materials,Vol.23,August,787-797

30. Brosilow, R. (1989), "Joining Processes for New Materials," Welding Design and Fabrication, August, 37-40.

31. Jahns, H. O. (1985), "Offshore Outlook: The American Artic," Mechanical Engineering, May, 76-82.

32. Gerwick, Jr., B. C. (1988), "Concrete Marine Structure," in "Materials for Marine Systems and Structures," (D. F. Hasson and C. R. Crowe, eds.), Academic Press, 351-387.

33. Anon (1972), The Structural Use of Concrete, British Standards Institute, CP 110, Her Majesty's Stationary Office, London.

34. Anon (1977), Recommendations for the Design of Sea Structures in Reinforced or Prestressed Concrete, 3rd Edition, Federation Internationale de la Precontraite, Paris.

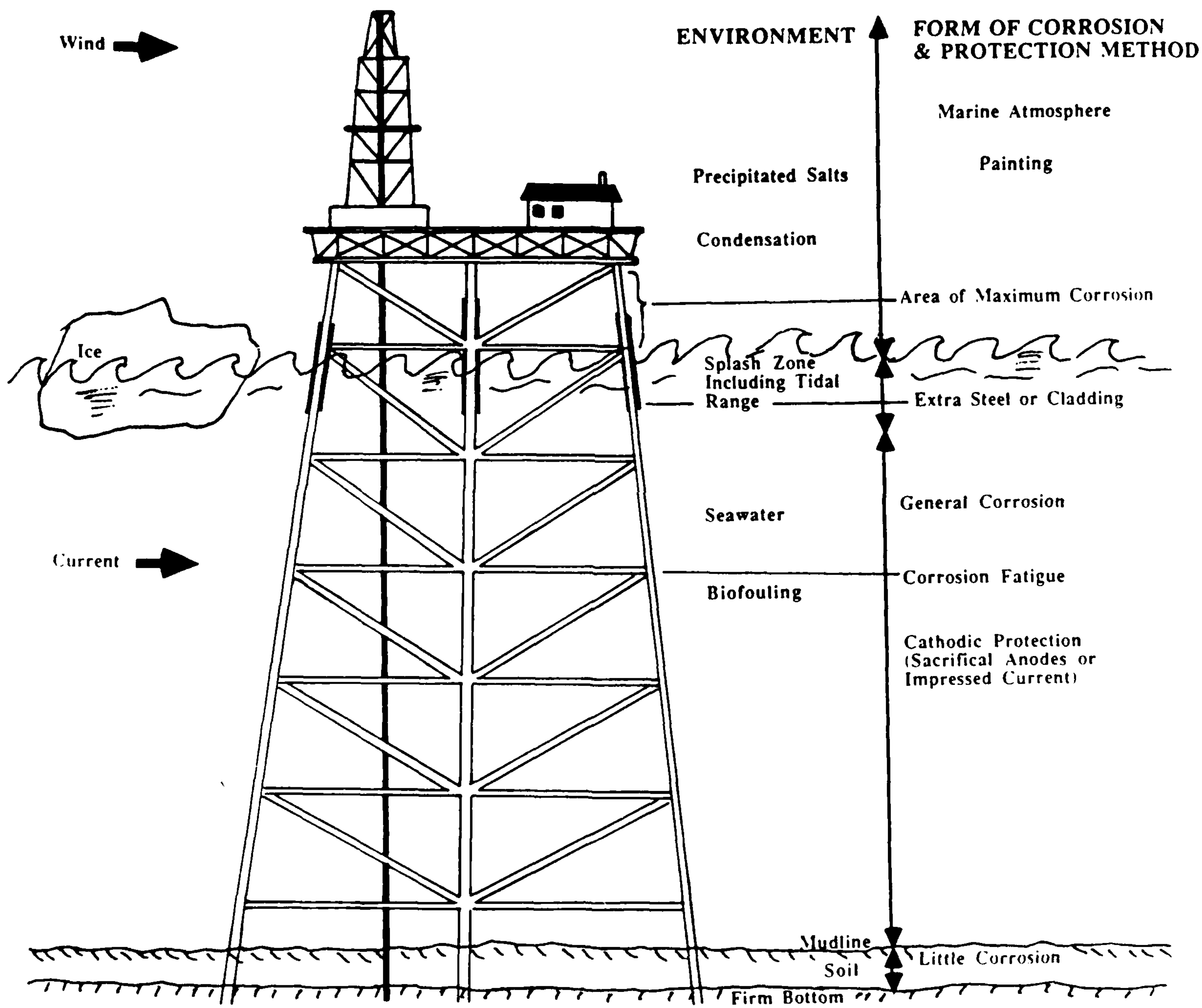

Figure 1. Environmental Effects on Marine Structures

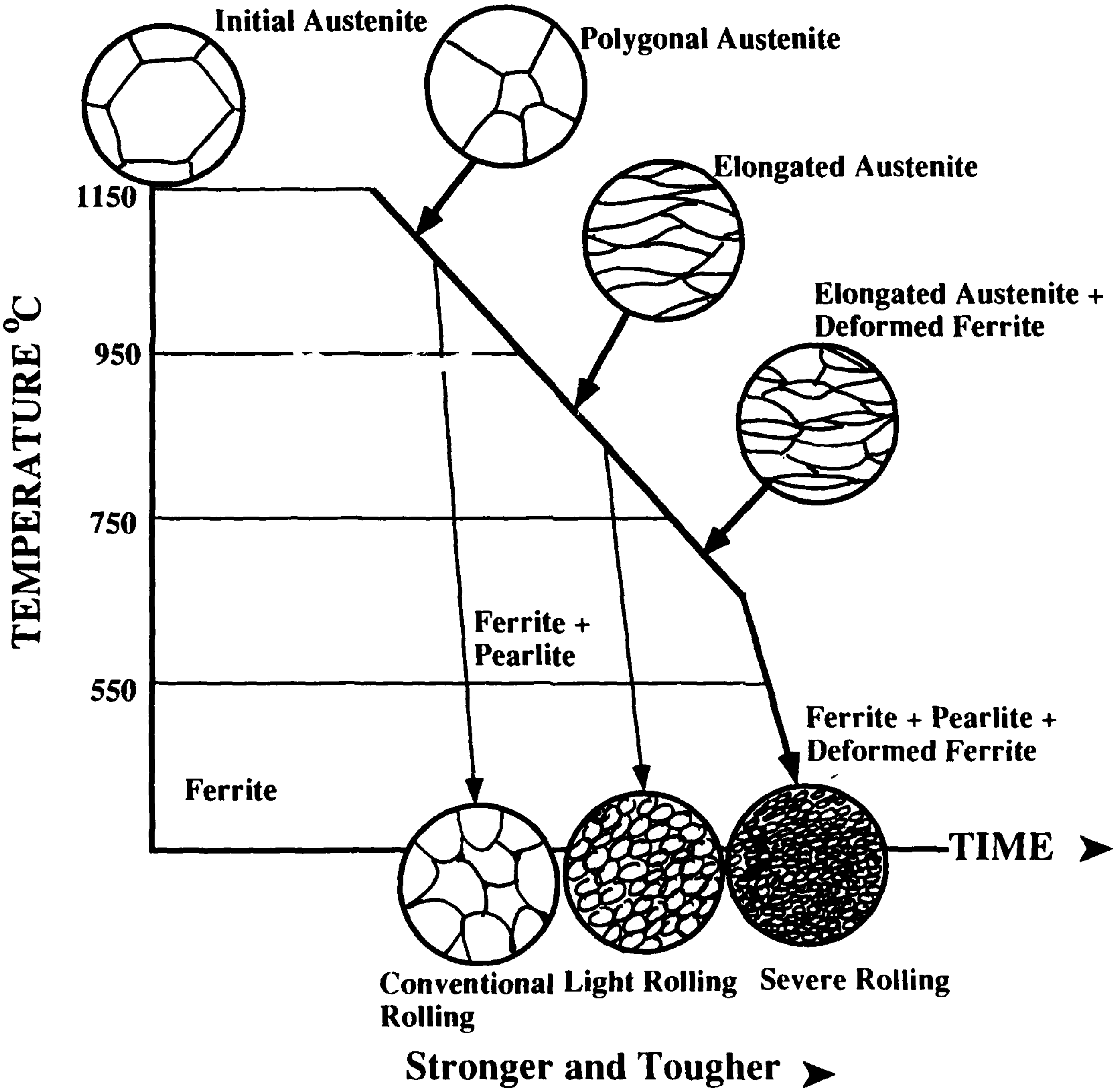

Figure 2. The Effect of Thermal Mechanical Control Processing on the Grain Size of Steel

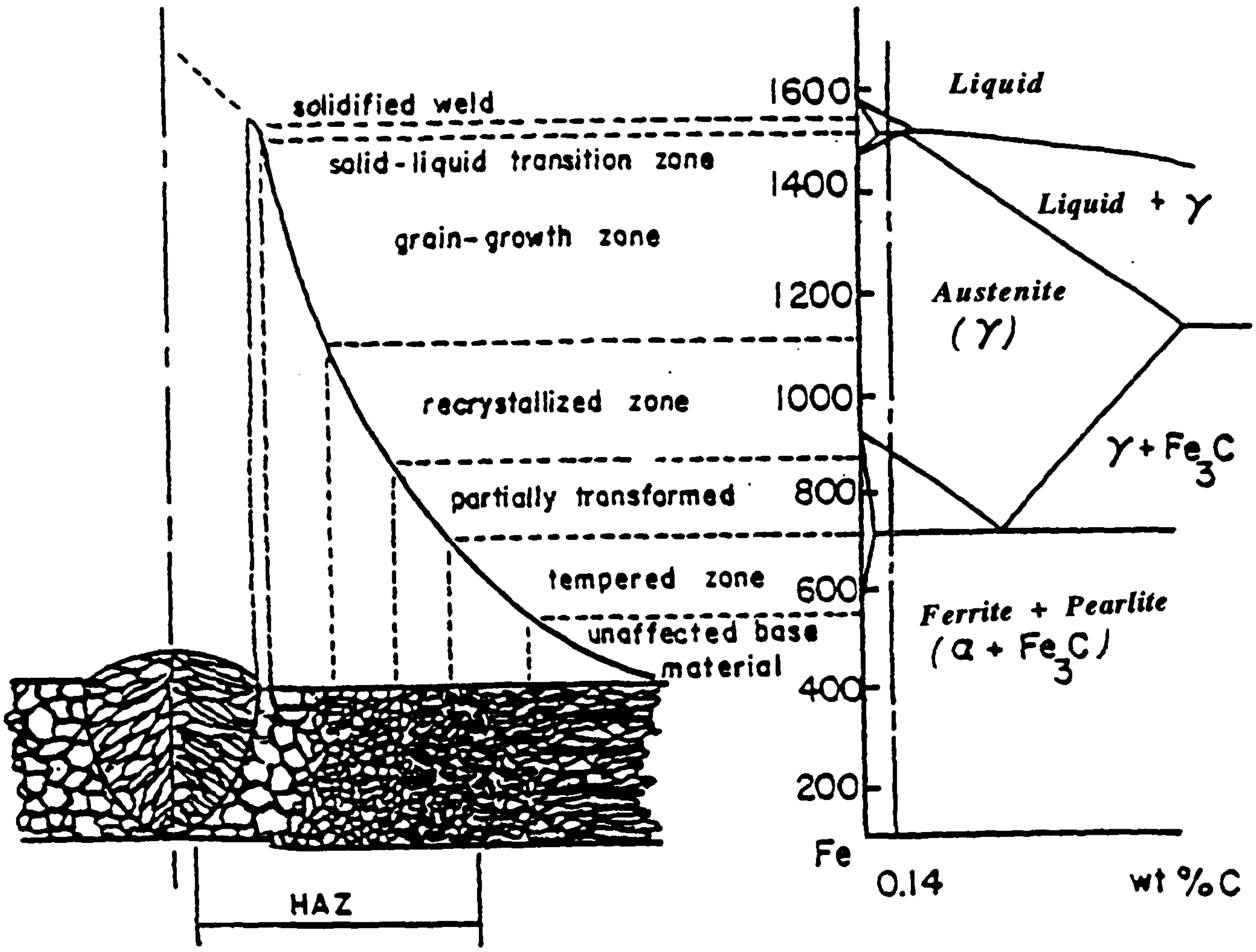

Figure 3. Schematic of the Cross-Section of a Weld and Its Relation to the Iron - Carbon Phase Diagram

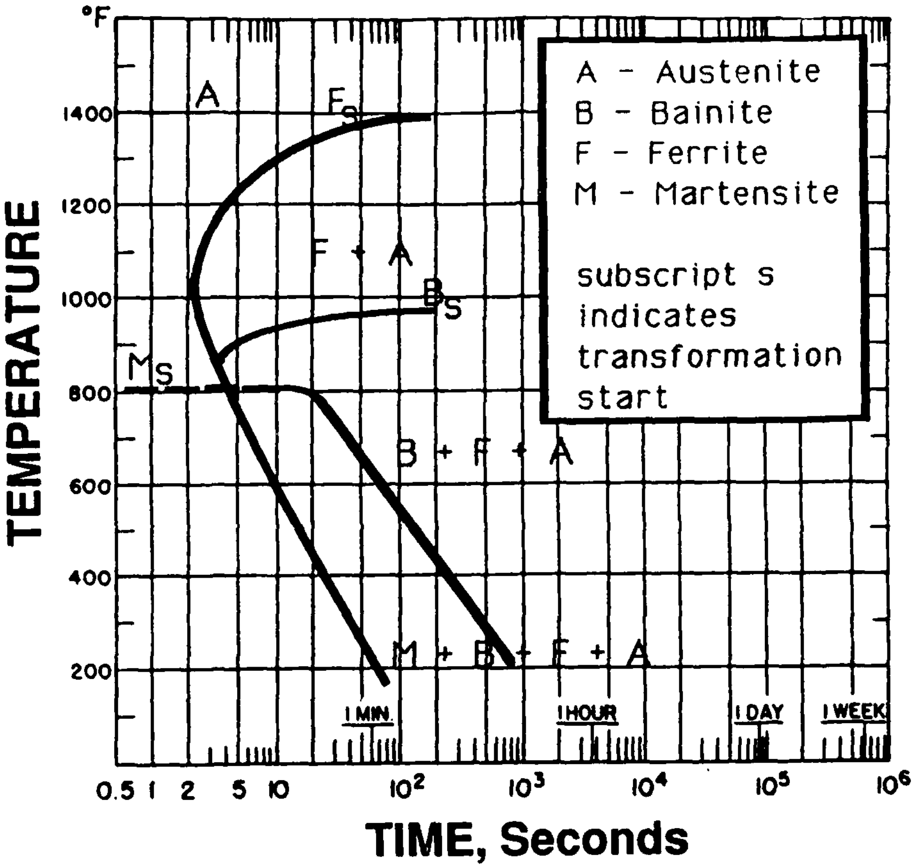

Figure 4. Schematic of the Continuous Cooling Transformation (CCT) Curve for a Steel

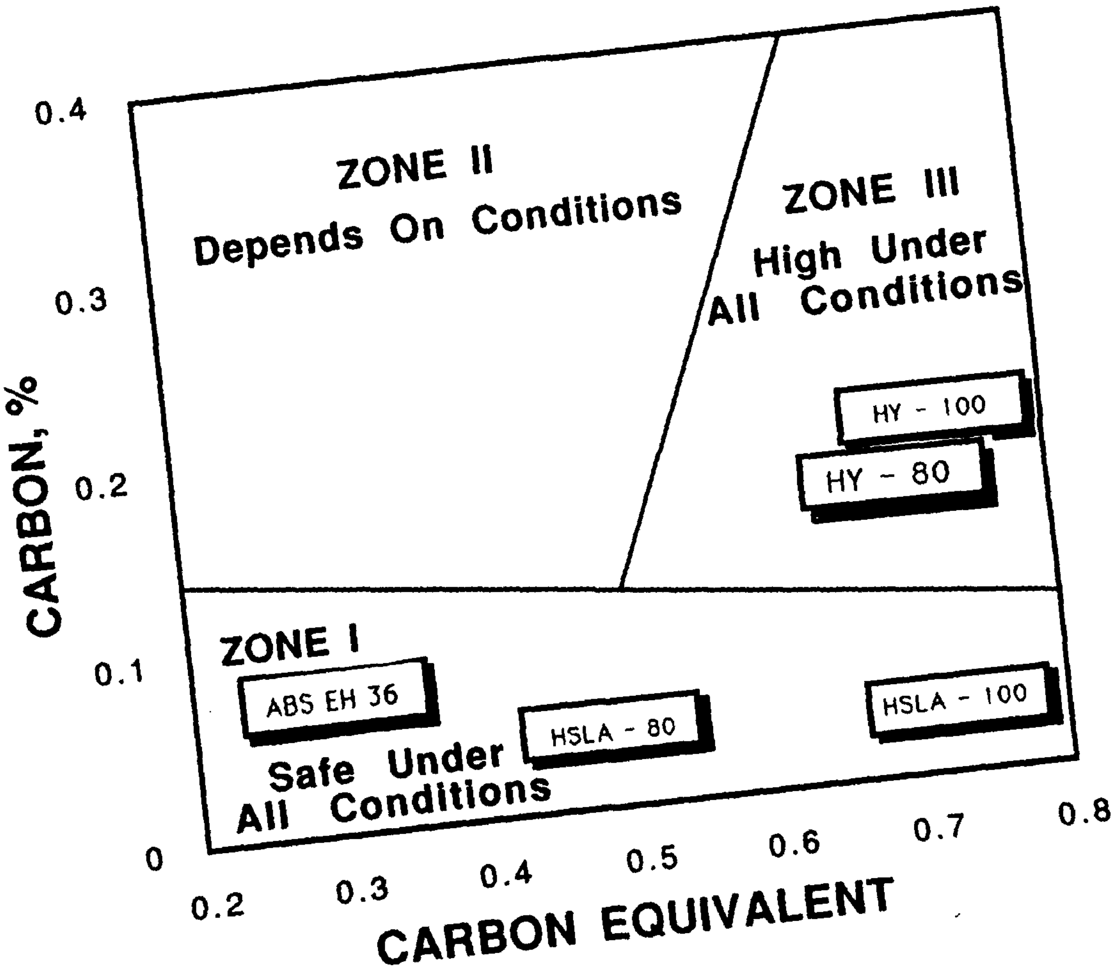

Figure 5. Graville Diagram Showing the Influence of Carbon and Carbon Equivalent on the Susceptibility to HAZ Cracking of Steel Plate

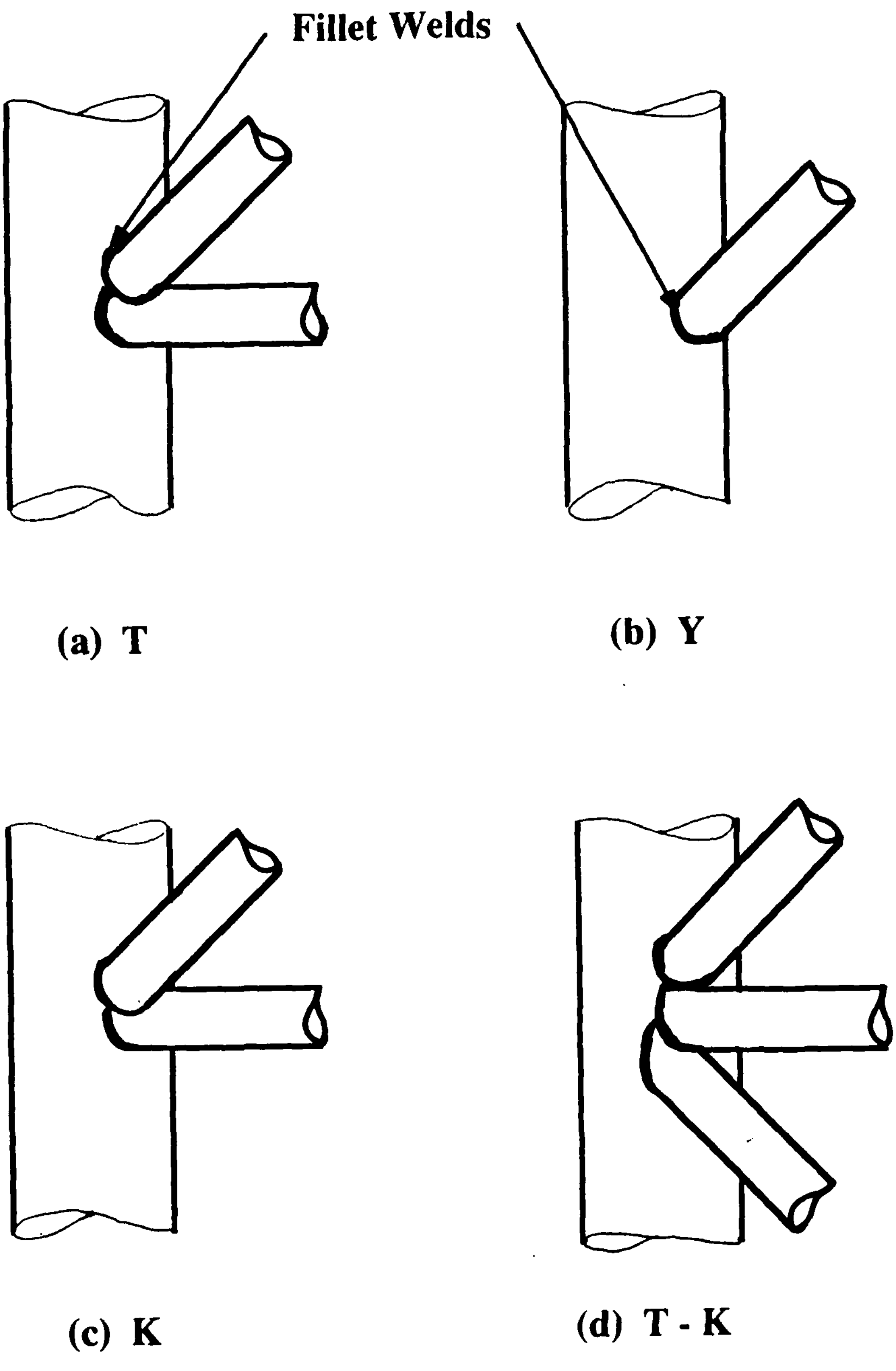

Figure 6. Types of Weld Joints Used in Tubular Construction

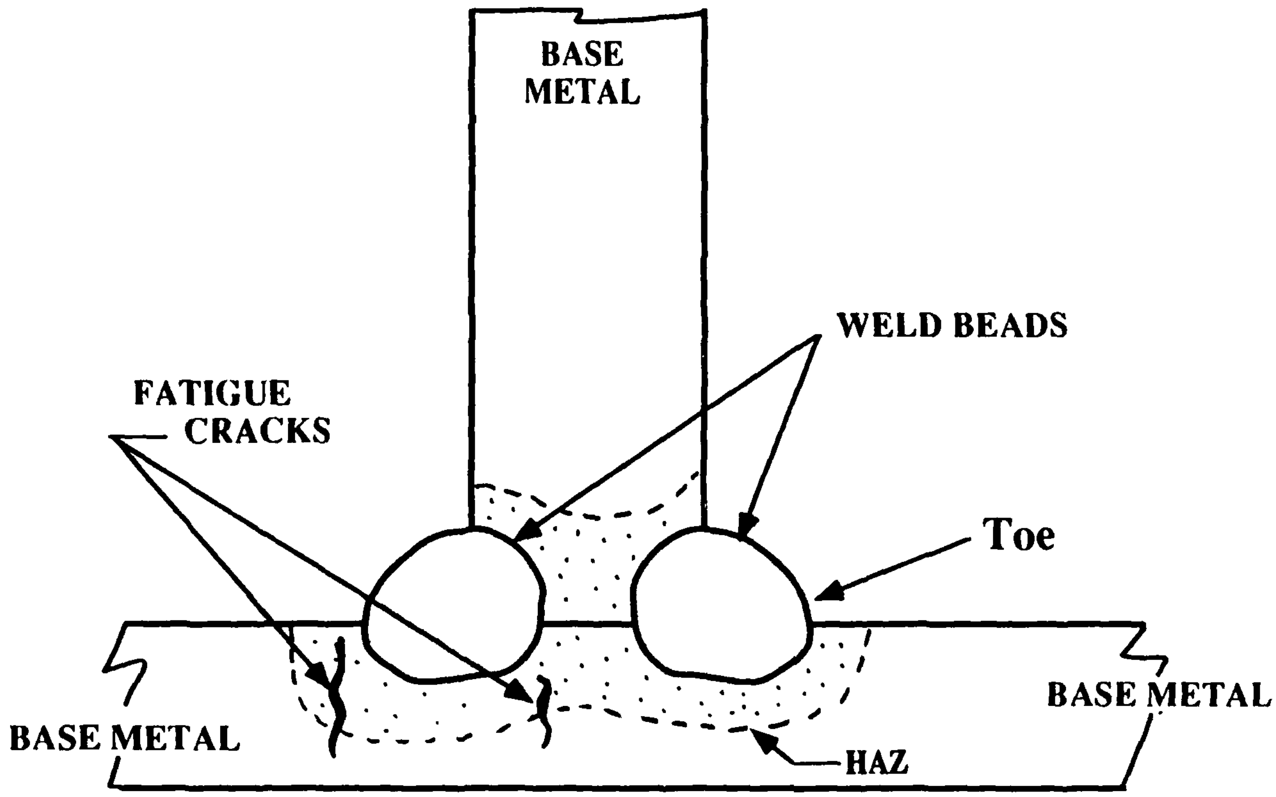

Figure 7. Schematic Showing the Typical Location of Fatigue Cracks in Marine Construction

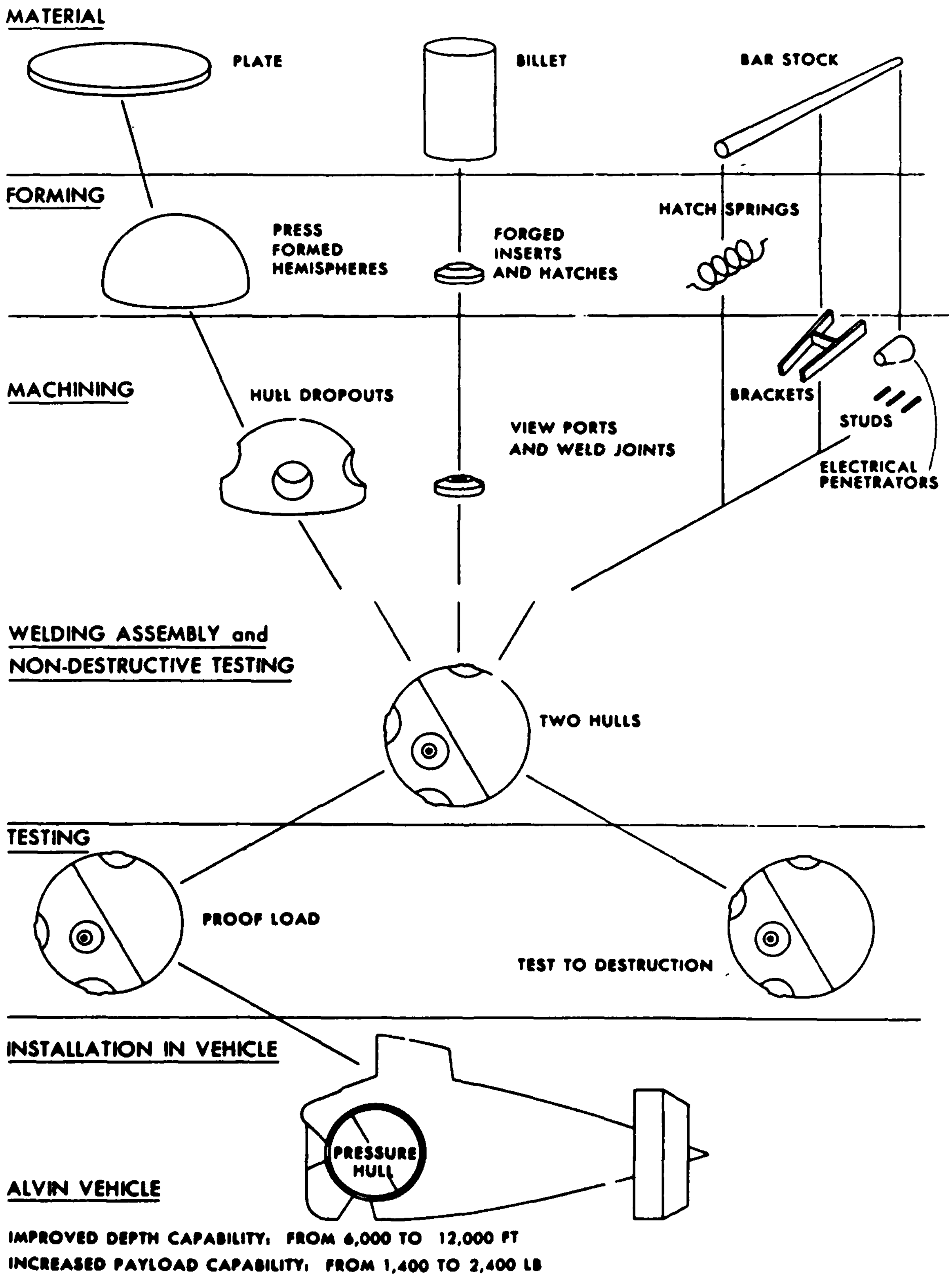

Figure 8. Steps in Fabricating the Titanium Pressure Hull for DSRV ALVIN. (Courtsey David Taylor Research Center)